Orbiting Starshade Imaging Simulations

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SISTER is a Matlab-based, versatile tool designed to provide accurate, diverse starshade astrophysical simulations.

It allows for controlling a set of instrument and system parameters : (1) the starshade design and position, (2) the exoplanetary system, (3) the optical system (telescope) and (4) the detector (camera).

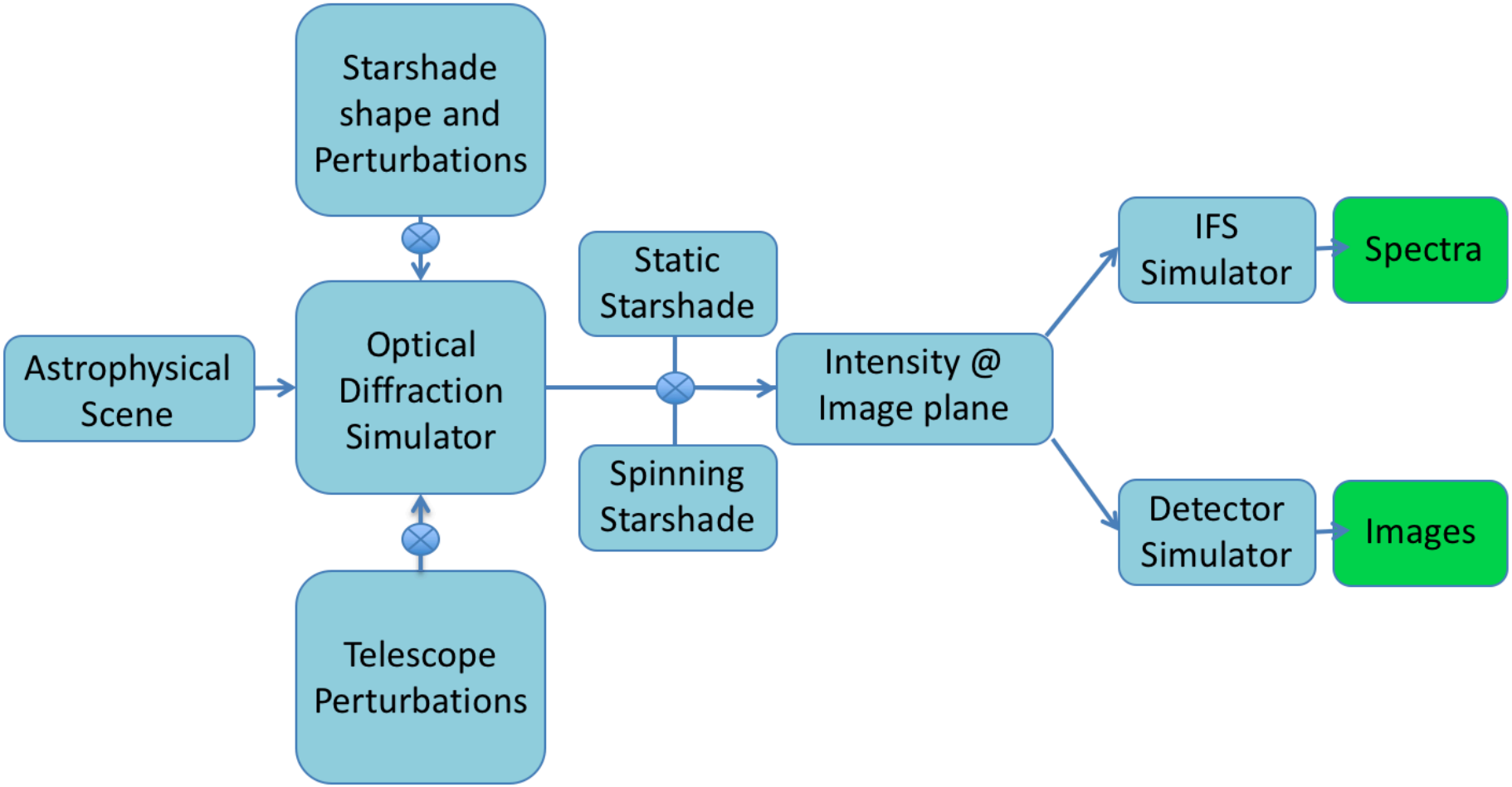
There is a built-in plotting software added, but the simulations may be stored on disk and plotted with any other software.

SISTER is an open source, well-documented project that will evolve with starshade.

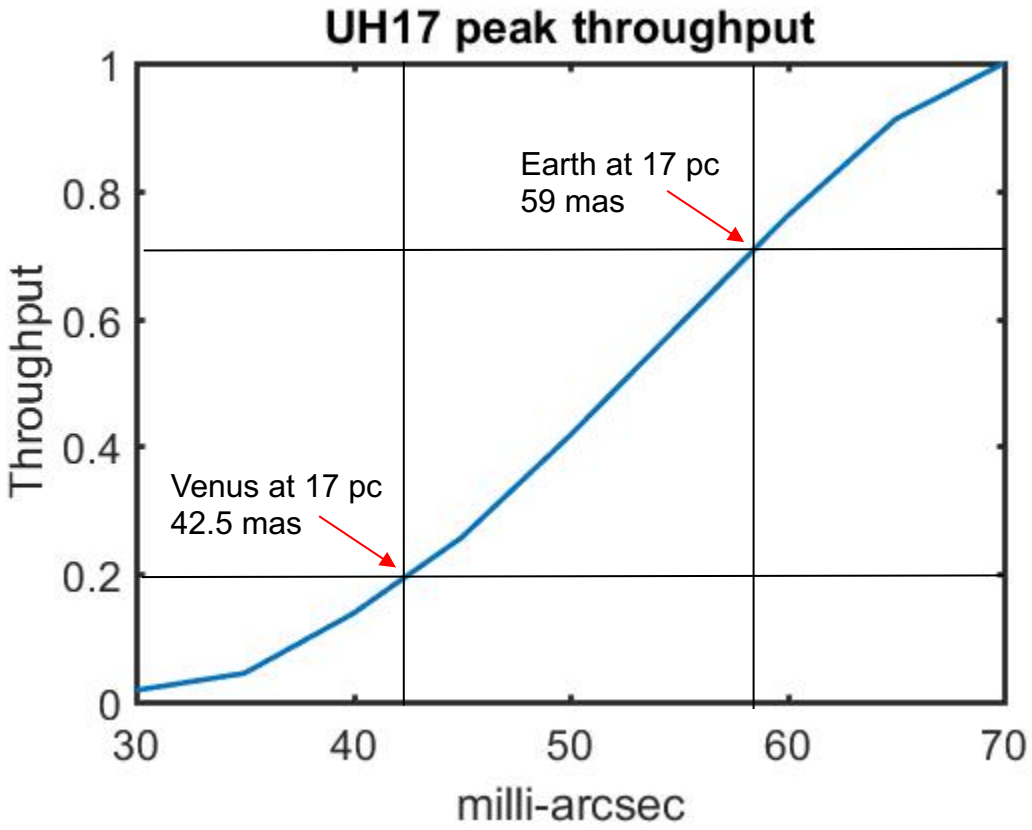
Sister.Caltech.edu

SISTER does NOT have built-in capabilities for atmospheric turbulence. Simulations with varying Strehl Ratio were done with independent programming.

SISTER Block Diagram



Starshade Planet Signal Throughput

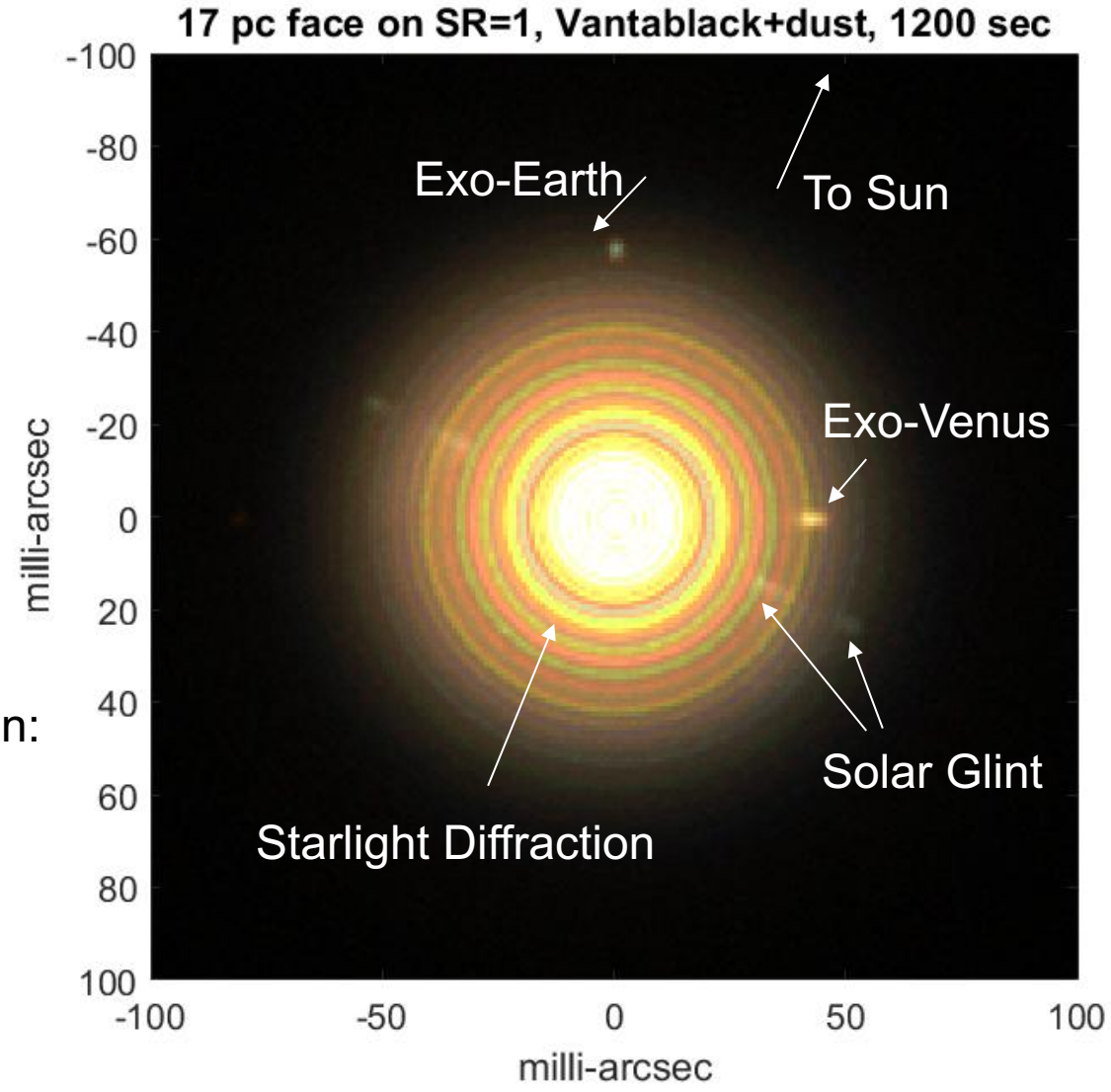


Measured by propagating light from a point source positioned at a range of angles behind the starshade. λ600-700 nm.

Imaging a Solar System at 17 pc

Solar type star, V=6

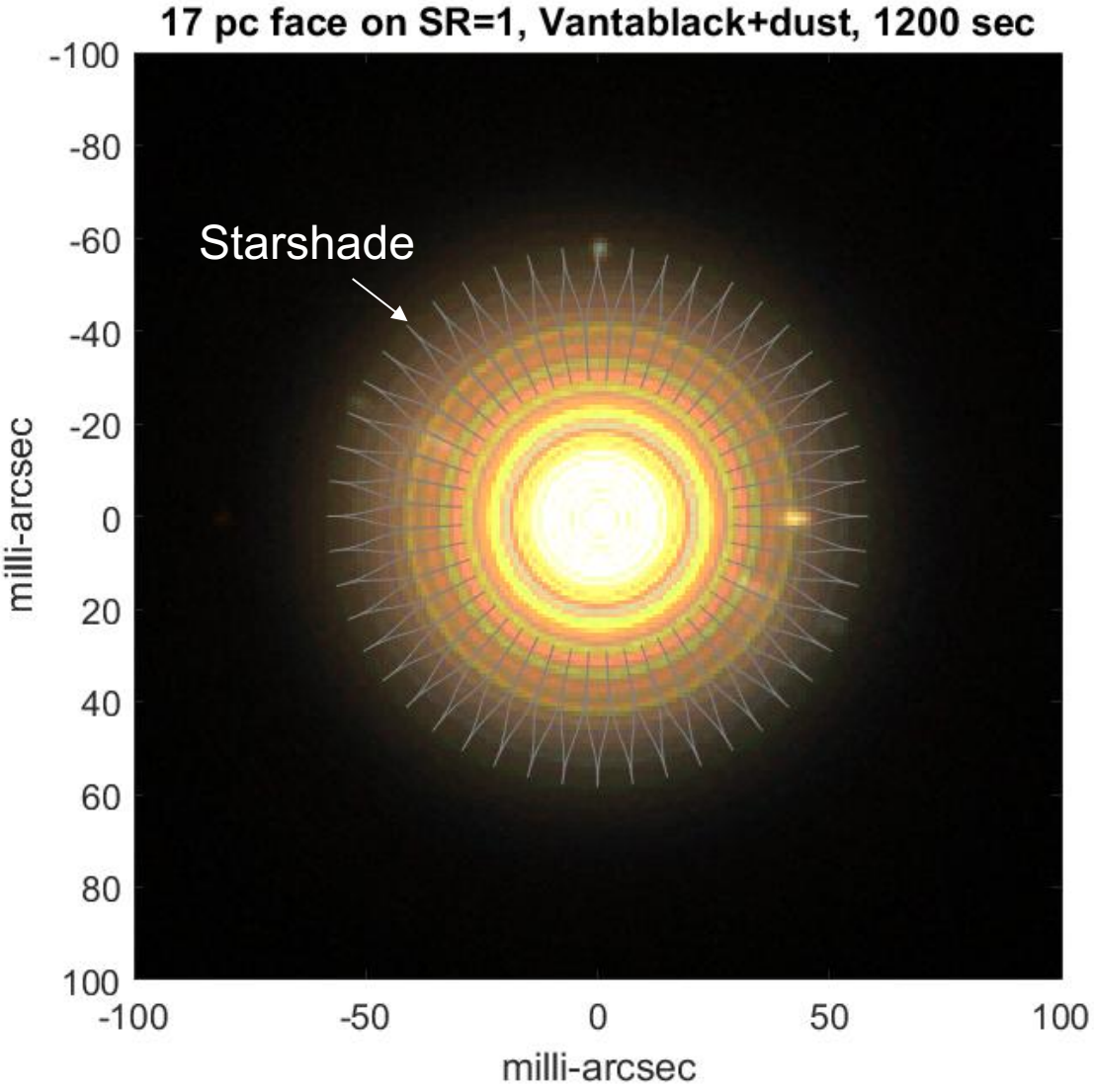
Three Bands:
400-500 nm
500-600 nm
600-700 nm



Starlight Diffraction:
Peak 8×10^{-9}
Total 7×10^{-8}

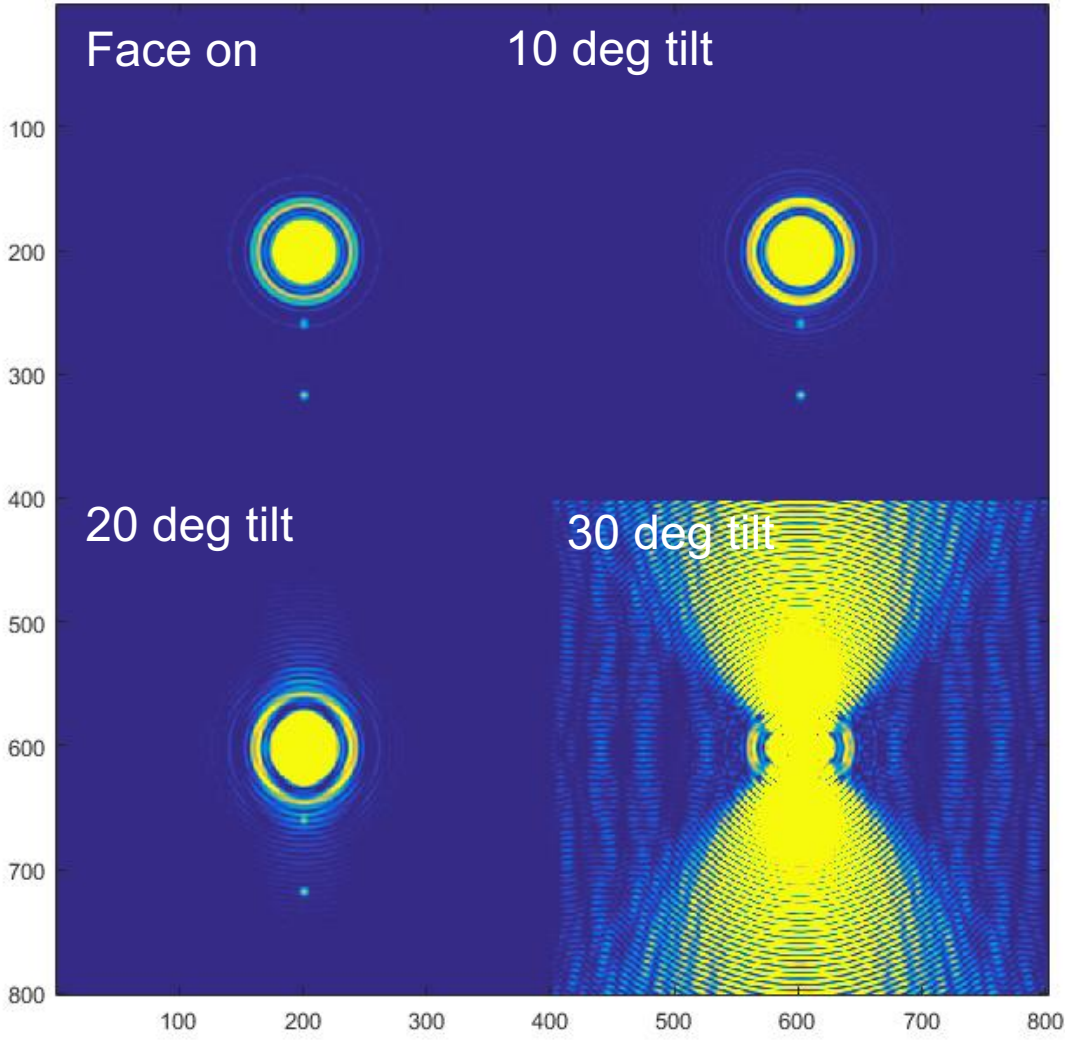
Imaging a Solar System at 17 pc

Solar type star, V=6



Tilting the stashade

Planets are 1e-10 contrast, at 58 mas and 116 mas.
Pixel scale 1 mas/pixel. Bandpass 900-1000 nm.

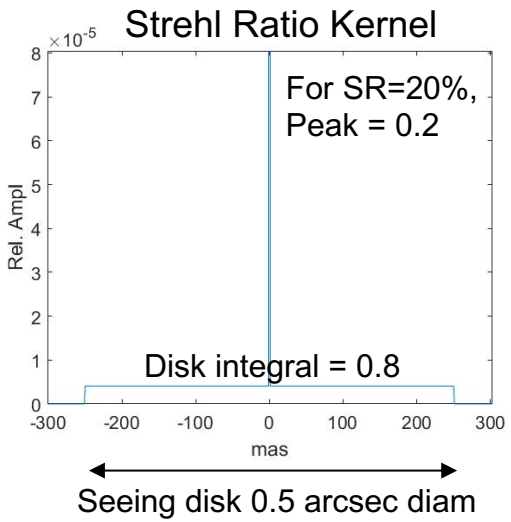


SNR for Exoearth Detection

- Effects included:
  - Earthshine on starshade, exozodi, Strehl Ratio, Starshade defocus, detector noise, spinning starshade.
- SNR = planet signal / sqrt(Planet + Background)
  - Computed in 5x5 mas box
  - Sum of 3 bands: 400-500, 500-600, 600-700 nm
- Earthshine
  - Integrated V=24 assuming 100% coverage with Vantablack (0.2% Total Hemisph. Refl.)
  - Assume V=24 in each band
  - Assume 1% coverage with dust, refl = 30% (WAG), so THR = 0.3% + 0.2% = 0.5%
  - Net V=23 for Vantablack + dust
  - For Black Kapton, integrated V=19 (per Eliad's calculation)
- Assume starshade is spinning
  - Averages solar glint
  - Averages throughput for a target 'between' petals
  - Averages Earthshine

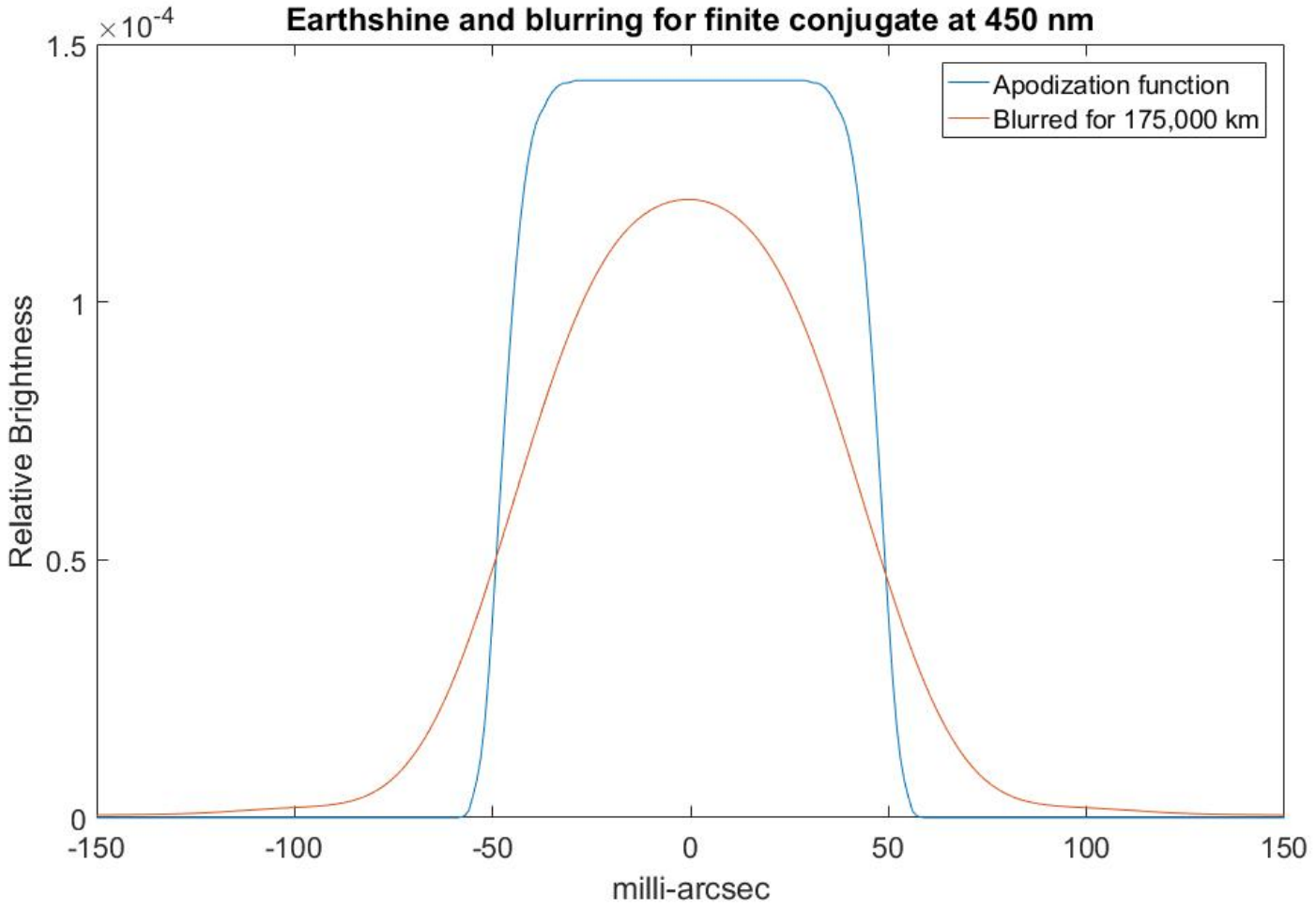
SNR for Exoearth Detection, cont'd

- Starshade Defocus
  - Telescope is focused on the planet. Starshade is at 1.75e8 m There is about 1 um of defocus at R=18.5 m.
  - The uniformly illuminated starshade is convolved with the defocus PSF of the telescope.
- Strehl Ratio
  - Assume PSF in two parts:
    - Diffraction-limited core with SR of the energy
    - Diameter=0.5 arcsec uniformly illuminated disk with (1-SR) of the energy
    - Convolve scene with this PSF prior to evaluating SNR
- Detector Noise
  - Simple model, 0.001 e-/hour, 3 e- read noise
- Total Throughput
  - 50% including QE



Eartshine, blurred for finite conjugate

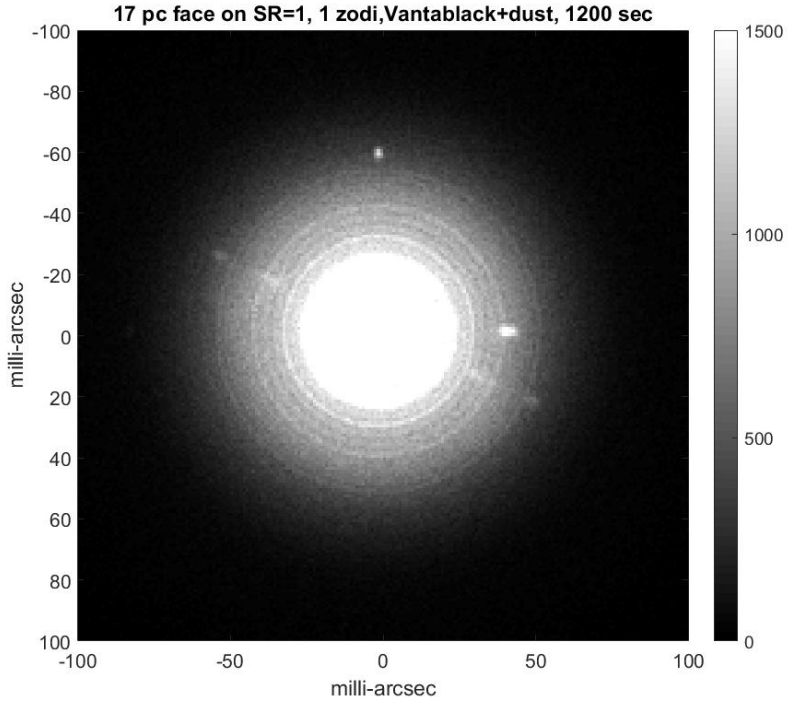
The starshade is 175,000 km from the telescope. This leads to 1 um of defocus (sag at the edge of the 39 m aperture). The resulting defocus blurs the starshade image.



Imaging at Strehl Ratio = 1.0 and 0.2

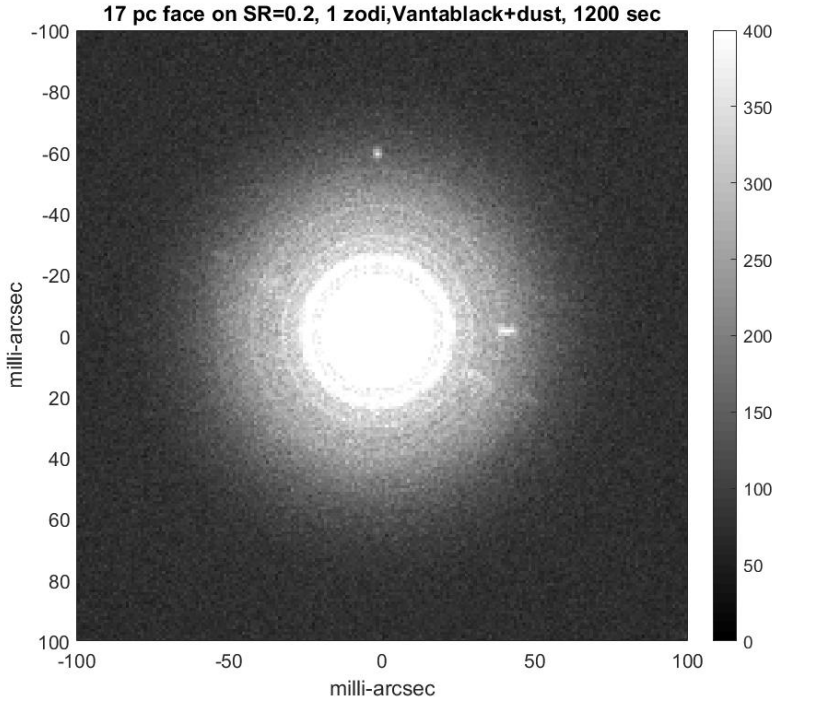
SR=1, 1 exozodi

0 - 1500



SR=0.2, 1 exozodi

0 - 400



White levels are counts in a 1200 s integration.
Optical throughput = 0.5.
Bandpass 400-700 nm.

With exozodi = 10 zodis, face on

SR=0.2, 10 exozodi

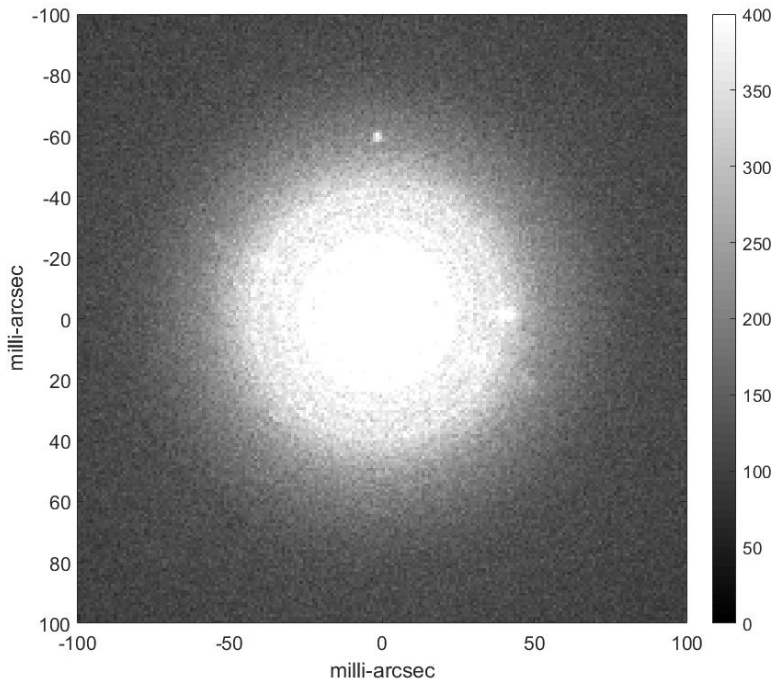
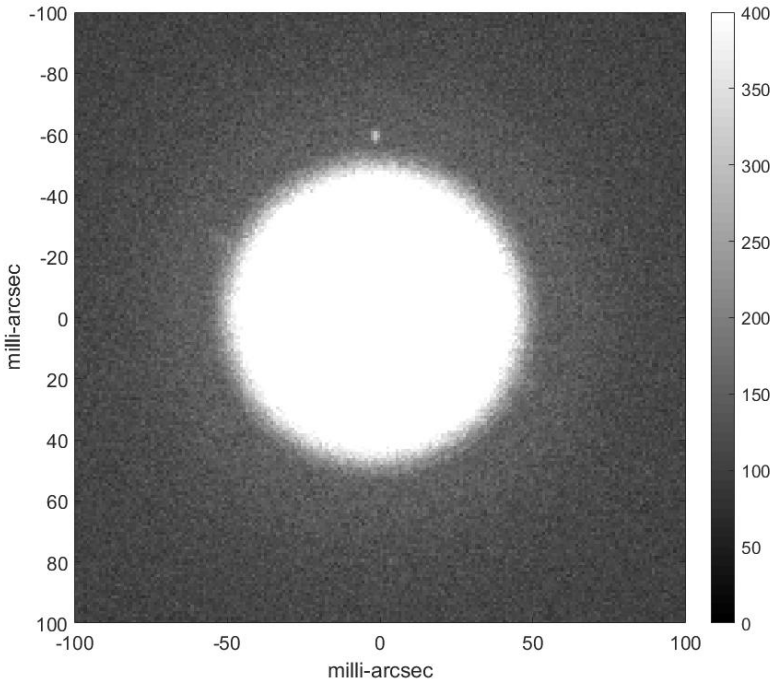


Image without blurring from finite distance

Without the blurring, the earthshine is localized to the starshade.

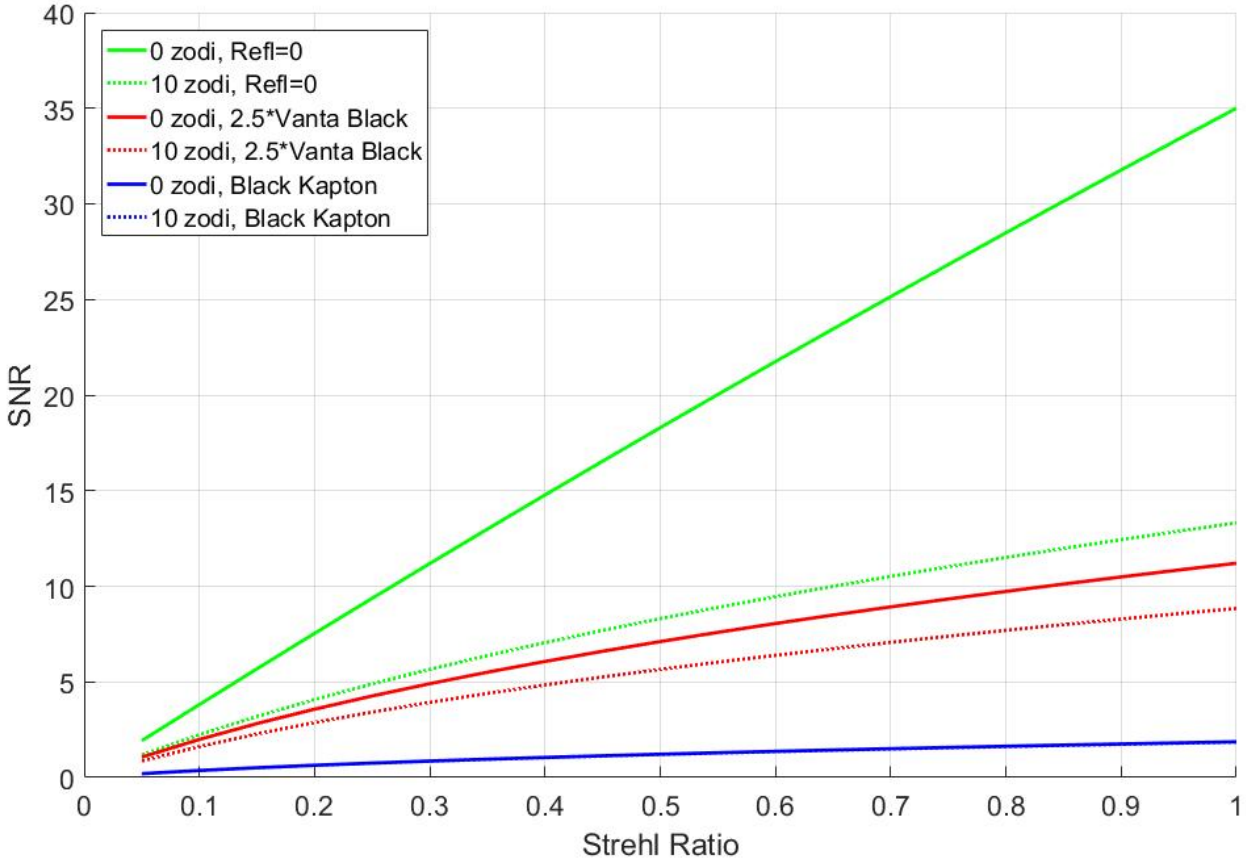
This would help with Earth detection, but would hurt Venus detection.

SR=0.2, 10 exozodi



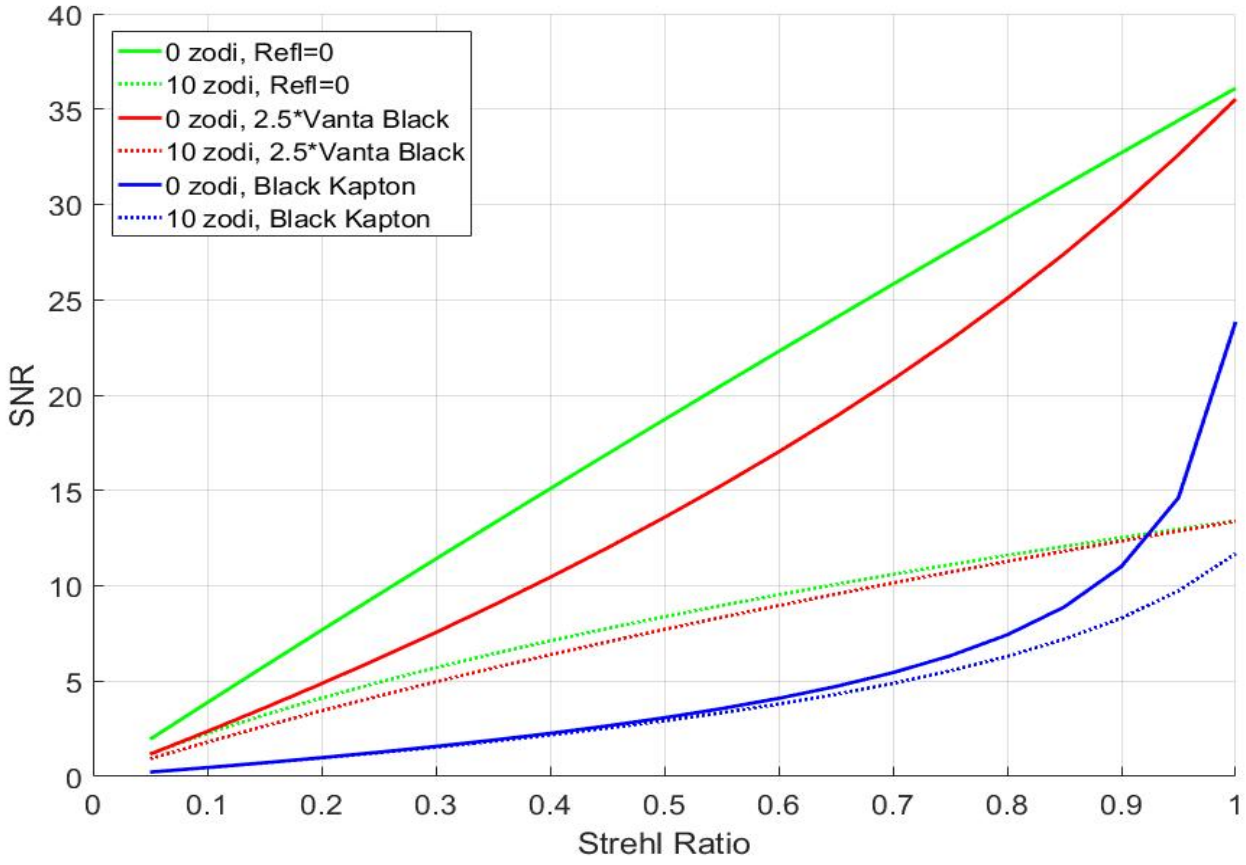
SNR for Exoearth Detection

- 1e-10 contrast planet at 17 pc. Separation = 58 mas.
- 50% throughput, 1200 sec exposure.
- With 0 exozodi and 10 exozodi, *inclined 60 deg*.
- Starshade Refl = 0, Refl = Vantablack+dust, Refl = Black Kapton



SNR for Exoearth Detection

- Same as the previous page, but without accounting for the defocus of the starshade.
- Without the defocus, and at high SR, the Earthshine is localized to the starshade region and doesn't affect (much) the planet SNR.



Conclusions

- Starshade must be very dark to minimize reflected Earth-shine
- Starshade may be able to tilt up to 20 deg. Definitely not 30 deg.
- Strehl Ratio of 0.2 is ok.
- SNR = 5:
  - Solar type star at 17 pc (V=6)
  - 1e-10 contrast planet (V=31)
  - 1200 s integration, 50% optical throughput including QE
  - SR = 0.25
  - Vantablack coverage (THR=0.2%) and 1% dust (THR=0.3%)

SISTER Instrument and Observational Parameters

1. **Telescope:** primary, secondary mirror, pupil, optical efficiency, pointing jitter.
2. **Detector model:** read noise, dark current, Filters, QE. For WFIRST, a full EMCCD simulator* can be run externally to SISTER, including CIC, aging, and other effects.
3. **Starshade mode:** spinning, or non-spinning.
4. **Non-ideal Starshade:** shape deformations –very many.
5. **Solar glint:** target Star-Starshade-Sun angle, and Sun angle about the orbital plane. Different petal edges depending on the starshade mode: razor, stealth.
6. **Local Zodiacal light:** surface brightness model from STSCI, helio-centric coordinates.
7. **Star:** the user may define any star (its sub-spectral type will be approximated by either 0 or 5, e.g. G3 will be G5). Or one may choose among any of the 2,347 stars from ExoCat (M. Turnbull, 2015).

SISTER Instrument and Observational Parameters

7. **Exo-dust emission:** any external model (for instance, from the Haystacks Project*). SISTER has as a proxy a very simple model scaled, rotated and resized from one run of Zodipic**.

8. **Planets and Keplerian orbits:** direct location, or 2-body motion with independent Keplerian parameters. No stability assessment.

9. **Reflected light from planets:** phase angle, phase functions (Lambert, Rayleigh).

10. **Extragalactic background:** deep field prepared by the Haystacks Project*.

11. **Proper motion and parallax:** given star coordinates and proper motion.

- **In progress:**

1. Flight formation of the starshade (Flinois et al. 2019, S5 Milestone 4).

2. Stellar background (nearly finished).